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CHARACTERISTICS OF FINES IN CORN: REVIEW AND ANALYSIS

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ABSTRACT

Fines (material smaller than whole corn kernels) are troublesome and continually increase as corn lots move from harvest to utilization. This article reviews characteristics of fines in corn, including constituents, size distribution, nutritive and economic values, density, and airflow resistance, and presents analysis of them. These characteristics are related to corn grading, handling, and processing issues. **KEYWORDS.** Corn, Fines.

INTRODUCTION

Fines (material smaller than whole kernels) are produced in corn as it moves from harvest to utilization. Increases in fines can be dramatic. Hill et al. (1979) followed a 9 550-t (10,510 t) lot of midwest corn as it was shipped to Rotterdam. The lot contained 3.6% broken corn-foreign material [BCFM-material that can pass through a 4.8-mm (12/64-in.) round-hole sieve, plus all matter other than corn that remains in the sieved sample] at loading on Lake Erie and 15% BCFM as delivered in Rotterdam. At this point, 1089 t (1,198 ton) of BCFM had been generated in the lot during shipment!

Size of fines in this article, except for dust, is defined in terms of sieve openings which will and will not allow the material to pass. Grain dust particle size was determined by the forward light scatter method.

Fines cause many problems. They make the corn more difficult to aerate (Grama et al., 1984), they increase the rate of spoilage (Kalbasi-Ashtari et al., 1979), they segregate from whole kernels under a filling spout (Stephens and Foster, 1976), and they are a favored location for production of aflatoxin (Shotwell et al., 1972). Presence of fines is the grain-quality problem most commonly mentioned by grain elevator/storage facility managers (Stroshine, 1989). Fines are the most likely cause of a drop in grade during shipment (Hill et al., 1979). They must be removed before wet milling (May, 1987) and dry milling (Alexander, 1987). Fines existing as dust (solid particles that become airborne) can, under certain

conditions, constitute fire, explosion, and health hazards (Martin, 1981; McLean, 1992).

The U.S. Grades and Standards define the corn quality factors that relate to particle size. As noted earlier, anything that passes through the 4.8-mm round-hole sieve is "fines" by this measure. Nearly all previously cited authors recognized, however, that there were broken pieces larger than 4.8 mm (12/64 in.) diameter. The BCFM sieve was originally 5.6 mm (14/64 in.) and the material through it was called cracked corn and foreign material. It was changed to the present 4.8-mm size in 1921 (Hill, 1990). An additional definition was created in 1987. Broken corn (BC) passes through the 4.8-mm sieve but not a 2.4-mm (6/64-in.) sieve. Foreign material (FM) is material which passes through the 2.4-mm sieve, plus all matter other than corn that remains on top of the 4.8-mm sieve (Miller, 1987). Presently, BC and FM are listed as information but do not establish numeric grade. Their summation, BCFM, is still the grade-determining particle-size factor for corn. There has been call recently to change the grades (NAEGA, 1986). A summary of corn fines and their properties is needed to evaluate potential actions.

This article is a review and analysis of reported characteristics of fine material (material smaller than whole kernels) in corn, with application to corn handling and corn grading.

CONSTITUENTS AND SIZE DISTRIBUTION OF FINES IN CORN

Hill et al., (1982) analyzed 1,080 samples of corn from Illinois country elevators and subterminals in 1976 and 1977. Table 1 lists constituents found in these samples, along with their size distribution. Constituent category was determined by microscopic examination. Note that even the smallest material was predominantly corn broken into small pieces. The noncorn particles were most concentrated in sizes 4.0 mm (10/64 in.) and smaller. This material contained 58% of the total noncorn weight in the sample. The BCFM contained 69% of the noncorn weight.

Several studies have reported concentrations of fines sizes in market corn. These data are summarized and averaged in Table 2. The percentage passing through a 4.8-mm round-hole sieve, the current BCFM sieve, is the reference base. Amounts passing through other sieve sizes are expressed as percentages of the weight passing through the 4.8-mm sieve. As an example, in the bottom (averages) line, 19.2% of what is now BCFM would pass through a 2.4-mm sieve. This is the sieve that was tentatively chosen to define corn FM. The remaining 80.8% of BCFM is

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TABLE 1. Constituents and size distribution of 1976 and 1977 corn samples delivered to Illinois country elevators and subterminals (after Hill et al., 1982)

	Size Ranges*							
	Corn		BC			FM		
	(mm)	> 6.0	6.0	4.8	4.0	3.2	2.4	1.8
	(in.)	> 15/64	15/64	12/64	10/64	8/64	6/64	4.5/64
Size Distribution of Corn Samples (% by Weight)								
		96.17 (2.27)	1.94 (0.76)	0.73 (0.46)	0.51 (0.44)	0.29 (0.29)	0.13 (0.16)	0.23 (0.37)
Constituent	Percentage in Material That Passed Through 4.8-mm Sieve	Distribution of Constituents in Each Size Range (%)						
Corn†	87.4 (11.2)‡	99.95	98.31	96.50	91.98	89.1	85.24	77.61
Corn by-products §	10.6 (9.8)	0.03	1.02	2.60	5.06	8.09	12.99	20.47
Weed seeds	1.7 (5.0)	0.02	0.66	0.88	2.96	2.42	0.90	1.73
Dust and inert material	0.3 (1.5)	0.00	0.02	0.03	0.03	0.38	0.87	0.29
	100.0	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Percentage of total noncorn kernel material	69	17	13	11	16	13	8	21

* Size of particles in each category lies between that round-hole sieve size and the next smaller one.

† Material originating on corn kernel.

‡ Values in parentheses are standard deviations.

§ Non-kernel material originating on corn plant.

|| Material not in other categories.

between 4.8 mm and 2.4 mm and would be broken corn. An important point shown by Table 2 is that the relative concentration of various particle sizes remains constant even though the actual amount of fines increased steadily with repeated handling. For example, export lots consistently had more BCFM than country elevator lots, but their relative concentrations of the sizes were not different.

The amount of BCFM in corn delivered to country elevators was less than 2% in all reports. Other studies have found the same low concentrations of BCFM at country elevators (Hurburgh and Moechnig, 1984; Hurburgh et al., 1983; Hurburgh, 1984). Increased discount for BCFM (or for any particle size designation) will be of limited effectiveness in mitigating handling breakage because farm-delivered grain has such small amounts, regardless of future breakage potential.

The following equation represents the averages from Table 2:

$$P_i = e^{0.6616S_i' + 1.455} \quad (1a)$$

where P_i is the percentage of the weight classified as BCFM passing through sieve size, and s_i' is the round-hole sieve size (mm).

$$(1.2 \leq s_i' \leq 6.4)$$

In conventional units,

$$P_i = e^{0.2625s_i' + 1.455} \quad (1b)$$

where s_i represents the round-hole sieve size (64th in.)

$$(3 \leq s_i \leq 16)$$

Figure 1 shows the Table 1 averages, along with the fitted function line.

The percentage of the lot weight that would pass through any round-hole sieve is then:

$$\rho_i = \frac{P_i B}{100} \quad (2)$$

where B is the percentage BCFM, and ρ_i is the percentage of total weight passing through a given round-hole sieve size. The percentage between any two screen sizes, s_i and s_{i-1} , is:

$$\rho_i - \rho_{i-1} = \frac{(P_i - P_{i-1})B}{100} \quad (3)$$

where P_i and P_{i-1} are calculated from equation 1a or 1b.

Assuming 100% cleaning efficiency (total cleanout) and that any material smaller than 6.4 mm is fines, the relative concentration of any two size ranges, s_i to s_{i-1} and s_{i-1} to s_{i-2} , will be (in the cleanings):

$$C_r = \frac{\rho_i - \rho_{i-1}}{\rho_{i-1} - \rho_{i-2}} = \frac{P_i - P_{i-1}}{P_{i-1} - P_{i-2}} \quad (4)$$

with the appropriate substitution of equation 1a or 1b or actual size data. Table 3 lists the predicted size distribution of corn fines (fines defined as less than 6.4 mm).

If cleanout is not complete, then an efficiency factor is introduced, for example $E_{i,i-1}$, $E_{i-1,i-2}$ (as decimals), and:

$$C_r = \frac{E_{i,i-1} (P_i - P_{i-1})}{E_{i-1,i-2} (P_{i-1} - P_{i-2})} \quad (5)$$

For example, suppose the uncleaned corn contains 1.0% FM ($P_{i-1} - P_{i-2}$) and 3.0% BC ($P_i - P_{i-1}$) and the cleaner is operating at 90% and 60% efficiency, respectively. The relative concentration of BC to FM in the cleanings will be:

$$C_r = \frac{0.6 (3.0)}{0.9 (1.0)} = 2.0$$

This is more concentrated in small particles than was the uncleaned corn.

The efficiency of a cleaner is related to screen size, in that near-fits are removed less efficiently than smaller particles (Quinn, 1987; Hurburgh et al., 1989). Equations 1a or 1b and 5 allow prediction of the relative

TABLE 2. Summary of data on corn fines size distribution

Ref.	Data Source	(mm) (in.)	Percentage through 4.8 12/64	Material Through Sieves*, as a % of that Through 4.8-mm (12/64-in.) Sieve									
				6.4 16/64	6.0 15/64	5.6 14/64	4.8 12/64	4.0 10/64	3.4 8.5/64	3.2 8/64	2.4 6/64	1.8 4.5/64	1.2 3/64
7	Export shipments 1974-75		3.28	246.5		100.0			44.4		21.5		6.4
18	Country elevator receipts, 1975 IA		1.24		301.6		100.0			41.9			
18	Country elevator receipts, 1976 IA		1.64		259.8		100.0			39.0			
18	Country elevator shipments, 1975 IA		1.89		267.2		100.0			31.2			
18	Country elevators shipments, 1976 IA		2.05		256.1		100.0			37.1			
18	River terminal receipts, 1975 IA		1.32		285.5		100.0			34.8			
18	River terminal receipts, 1976 IA		1.54		278.6		100.0			35.7			
18	River terminal shipments, 1975 IA		1.75		282.9		100.0			39.4			
18	River terminal shipments, 1976 IA		2.40		265.4		100.0			52.9			
18	Export receipts by barge, 1975		2.71		237.6		100.0			41.7			
18	Export receipts by barge, 1976		3.08		229.2		100.0			40.9			
18	Export receipts by unit train, 1976		2.74		255.1		100.0			31.4			
18	Export shipments 1975		3.12		240.7		100.0			36.2			
18	Export shipments 1976		3.33		230.0		100.0			39.9			
9	Country elevator receipts, 76-77 IL		1.14		247.4		100.0	54.3		34.2	19.2	12.3	
9	Country elevator shipments, 76-77 IL		1.85		211.9		100.0	50.3		31.9	17.8	11.4	
9	Terminal receipts 76-77 IL		2.00		196.5		100.0	63.1		36.0	20.5	13.1	
9	Terminal shipments 76-77 IL		2.60		181.5		100.0	64.6		36.9	19.6	12.3	
8	Export shipments 78-79 IL		3.30				100.0			33.3		12.1	
6	Country elevator shipments, 1981 US		2.25	243.9		163.4	100.0	56.1		31.7	19.5	12.2	
10	Export shipment sublots, 1985		5.32	266.9			100.0	44.1		39.3	19.9		5.3
15	Hopper cars at origin, 1986 IA		2.11	273.5		152.1	100.0	62.1		29.8	16.1		
15	River terminal shipments, 1986 IA			213.6		139.9	100.0	60.7		33.4	18.5		
	Averages		2.39	248.9	248.6	151.8	100.0	61.6	44.2	36.8	19.2	12.2	5.8

* Assumed to be round-hole, except Reference 7 which was square mesh.

size distribution of cleanings, an important property in determining the value of cleanings as feed.

The concentration of fines in corn after cleaning also is important to the evaluation of cleaning and grade standards. Assuming that the grade standard is defined by some screen size s_g , which is removed at efficiency E_g , as a decimal:

$$\rho_{gf} = \frac{e^{0.6616 s_g + 1.455} B(1.0 - E_g)}{100} \quad (6a)$$

or, in conventional units

$$\rho_{gf} = \frac{e^{0.2625 s_g + 1.455} B(1.0 - E_g)}{100} \quad (6b)$$

An example application of this formula can be derived from the data on rotary cleaners presented by Hurburgh et al. (1989). For rotary cleaners operating at a flow density (ratio of grain mass flow rate to rate of cleaning area exposure) of 6 kg/m², cleaning efficiency was 55% for BCFM and 75% for FM alone. Table 4 shows

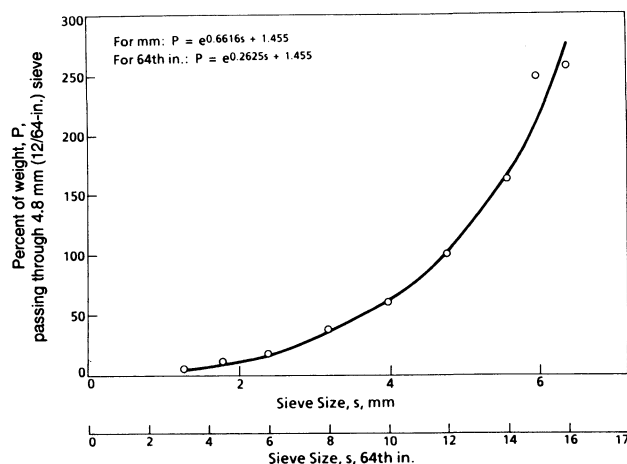


Figure 1—Weight of corn fines passing through round-hole sieves as a percent of weight passing through 4.8-mm (12/64-in.) round hole sieve.

the concentration of BCFM and FM before and after cleaning, and the relative concentration of FM to BCFM in these cleanings. The cleanings were more concentrated in the smaller particles because cleaner efficiency was better for smaller sizes.

Equations 1-3 also can be used to predict particle size concentrations after future handlings, with the only independent variable being the percentage points of increase in the BCFM grade factor.

Aspiration can be used to clean grain. It separates by drag force of air and not necessarily by size. Therefore, some of the material removed in aspiration may not be classed as objectionable against a size-defined grade standard. Al-Yahya et al. (1991) determined the size distribution of liftings removed by a Kice 6DT4 mini-aspirator from a stock of corn containing 4.0% BCFM distributed in the size fractions defined by Table 3. Results are shown in figure 2.

Air velocities were calculated for the 10-mm by 102-mm air intake slots. The greatest velocity (22 m/s) was selected to remove 100% of BCFM. It also took out nearly 35% of the whole corn (material over 6.4-mm sieve). The least velocity (8 m/s) was selected to take out

TABLE 3. Estimated particle size distribution in corn cleanings*

Size No.	Definition				% of Fines by Weight
	Through		Over		
	(mm)	(in.)	(mm)	(in.)	
1	6.4	16/64	5.6	14/64	39.0
2	5.6	14/64	4.8	12/64	20.8
-----BCFM = 40.2% -----					BC = 32.5%
3	4.8	12/64	4.0	10/64	15.4
4	4.0	10/64	3.2	8/64	10.0
5	3.2	8/64	2.4	6/64	7.1
-----BCFM = 40.2% -----					BC = 32.5%
6	2.4	6/64	1.8	4.5/64	2.8
7	1.8	4.5/64			4.9
-----BCFM = 40.2% -----					FM = 7.7%
					100.0

* Cleaning at 100% efficiency over a 6.4-mm round-hole sieve.

TABLE 4. Size distribution of cleaned corn and cleanings from rotary grain cleaners (after Hurburgh et al., 1989)

Uncleaned Corn		Cleaned Corn		Percentage FM in Cleanings	
% BCFM	% FM†	% BCFM* (E = 0.55)	% FM* (E = 0.75)	If E = 1.00‡	Actual‡
2	0.42	1.10	0.32	21	29
4	0.84	2.20	0.63	21	29
6	1.26	3.30	0.95	21	29

* From equation 6b, FM defined as material passing through a 2.4-mm screen.

† From equation 1b.

‡ From equation 4.

almost no (<1%) whole corn. At 13 m/s, the slowest velocity that would remove nearly all FM, the aspirator removed about 65% of the BCFM. This was comparable to the rotary-screen cleaners. Combination of equation 1a or 1b and the aspirator efficiency data, with B=4.0%, predicts that, at this airflow, the aspirator will remove about 5% of the material larger than BCFM.

That would be an economically objectionable loss. The rotary-screen cleaners removed about 1% of material larger than BCFM. We found no published data on the relative cleaning efficiencies of commercial cleaners in operation at grain elevators.

NUTRITIVE VALUE OF FINES

Hill et al. (1982) measured nutritive value of various particle sizes of corn fines and whole corn screened from the 1976 and 1977 crops. Martin (1981) studied grain dust from four Kansas elevators. Their results are shown in Table 5. Values for dust will be discussed in a later section.

Protein content increased with decreasing particle size. For fines passing through the 1.8-mm (4.5/64-in.) sieve, protein was more than two percentage points (20%) greater than for whole corn. This suggests that this smallest size fraction contains a large portion of high-protein germ.

The smallest fraction (through 1.8 mm) has by far the greatest ash content (4.59%). This again suggests a large

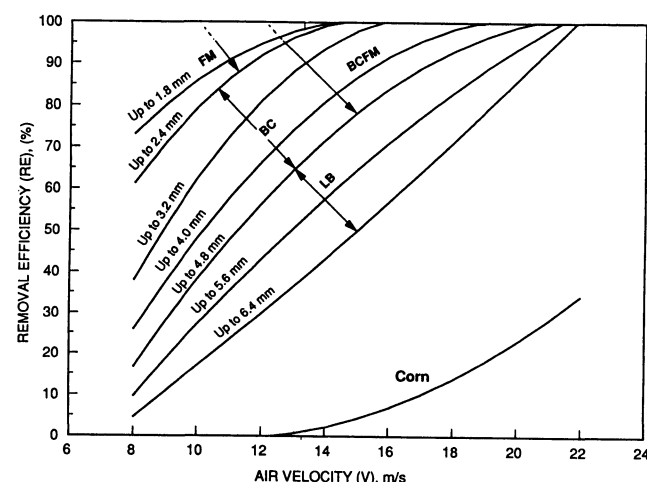


Figure 2—Cumulative size-removal efficiency (%) and air velocity (m/s) for eight sieve sizes when aspirating corn with 4.0% BCFM (after Al Yahya et al., 1991).

portion of germ material in this fraction, since germ material is about 10% ash and has ten times the ash content of any other kernel part (Ockerman, 1978). Table 1 values for constituents of the smallest fraction bear this out by showing that over 77% of this fraction originates on the corn kernel.

Al-Yahya et al. (1991) determined nutrient value of corn liftings removed by a Kice 6DT4 mini-aspirator from a stock of corn containing 4.0% BCFM with particle sizes distributed as given in Table 3. Figure 3 shows protein, oil, and starch of the liftings. Starch content of liftings was maximized at a low velocity; oil content was maximized at the greatest velocity. The protein content was the least defined, with no evident trend of variation with air velocity. Evidently high-starch particles have lesser terminal velocities and high-oil particles have greater terminal velocities.

AIRFLOW RESISTANCE AND DENSITY

Stored fines have considerable airflow resistance. When intermixed with grain, they also increase the airflow resistance of grain. Yang et al. (1990) measured airflow resistance and density of fines removed from corn by sieving. Experimental airflow-resistance data were fitted to this modified Ergun equation:

$$P = A \frac{\left(\frac{BD}{PD}\right)^2}{\left[1 - \frac{BD}{PD}\right]^3} V + B \frac{\frac{BD}{PD}}{\left[1 - \frac{BD}{PD}\right]^3} V^2 \quad (7)$$

where

- P = pressure drop per unit bed depth (Pa/m)
- V = superficial fluid velocity m³/m² min
- A, B = regression coefficients
- PD = particle density (kg/m³)
- BD = bulk density (kg/m³)

Figure 4 shows equation 7 plotted for each of the seven sizes, along with the shelled corn line from Shedd (1953). Sizes correspond to size numbers defined in Table 3. Equation coefficients are presented in Yang et al. (1990). Airflow resistance of each successively smaller fines size is

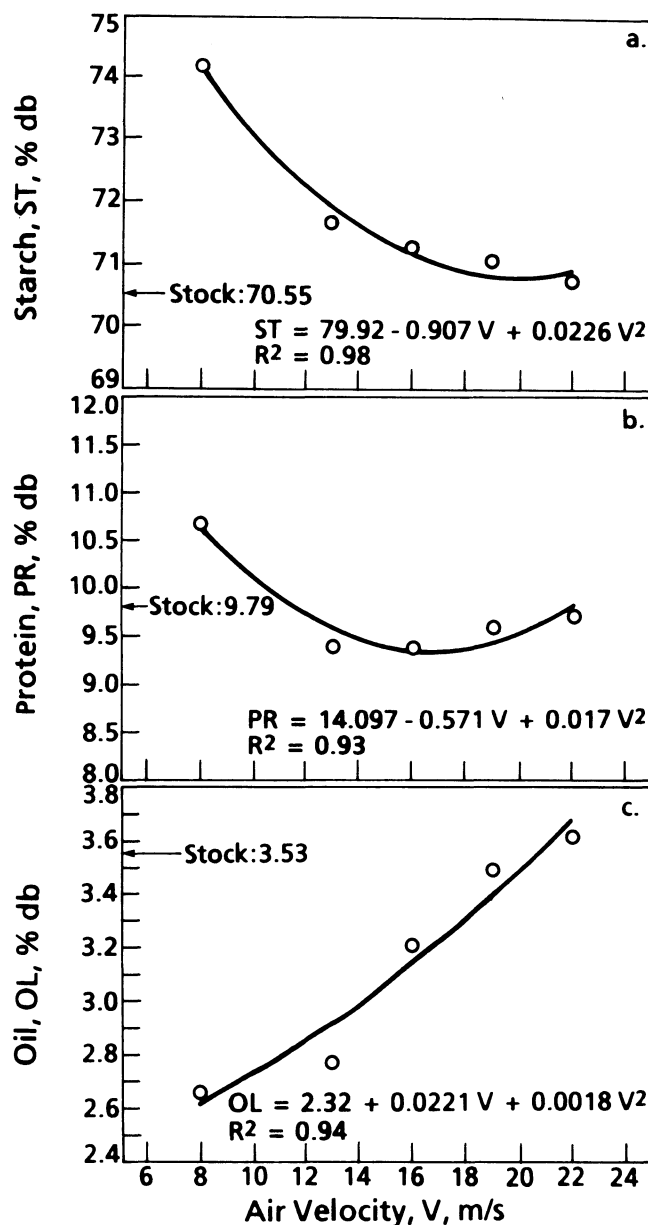


Figure 3—Starch, protein, and oil of liftings as a function of air velocity (Al Yahya et al., 1991).

TABLE 5. Nutritive properties of corn fines (adapted from Hill et al., 1982; Martin, 1981)

Property	Whole Corn (>15 / 64-in.)	6.0 mm* (15 / 64-in.)	4.8 mm (12 / 64-in.)	4.0 mm (10 / 64-in.)	3.2 mm (8 / 64-in.)	2.4 mm (6 / 64-in.)	1.8 mm (4 / 64-in.)	Dust
Crude protein (%)*	10.2	10.1	10.4	10.4	10.4	11.0	12.3	9.0
Ash (%)*	1.4	1.4	1.6	1.6	1.7	2.4	4.6	6.6
Oil (%)*	4.5	3.9	4.3	3.4	2.5	2.4	2.4	2.7
Crude fiber (%)*	2.2	2.3	2.6	2.9	3.5	4.2	5.9	8.1
NFE†, ‡ (%)	81.8	82.3	81.1	81.7	81.9	80.1	74.7	73.6
Digestible energy§ (DE)								
MJ / kg	16.45	—	15.81	15.57	15.30	15.03	14.84	—
kcal / lb	1786	—	1717	1691	1661	1632	1611	—

* Size of particles in each category lies between that screen size and the next smaller one.

† All percentages are on a dry basis.

‡ Nitrogen free extract; NFE = 100 – protein – oil – ash – fiber.

§ DE = Gross energy (calorimeter) – fecal loss.

greater. Size 7 fines (material that will pass through a 1.8-mm sieve) exhibit an air pressure drop about 40 times that of clean corn at an airflow of $0.1 \text{ m}^3/\text{m}^2 \text{ min}$.

Figure 4 also lists particle and bulk densities of each fines size. Particle density (measured with a Beckman 930 air comparison pycnometer) increased for each successively smaller fines size. Al-Yahya et al. (1991) reported a similar trend. All fines particle densities were greater than that measured for whole corn. The whole-corn density, when corrected to 15% moisture (Dorsey-Redding et al. 1990), was close to that reported by Dorsey-Redding et al. (1991) as the average for normal corn.

Bulk densities were measured after dropping fines a distance of 649, 1355, or 1990 mm into a 249-mm-diameter column. All fines bulk densities were less than that of whole corn (725 kg/m^3), but densities increased with drop height and decreased for smaller particle sizes.

These data illustrate the dilemma of using density (particle or bulk) as an indicator of screenings quality. Market practice has used test weight (bulk density) as the prime quality indicator for screenings (Brooks, 1978). Likewise, in whole corn, increasing (particle) density is an indicator of increasing hardness and increasing protein content (Dorsey-Redding et al., 1991). Yet, bulk density and particle density are inversely related in screenings. A better feed-value indicator than density is needed.

Grama et al. (1984) measured the airflow resistance of corn containing various amounts of fines. Effects of fines

were expressed as clean-corn multipliers (CCM). The product of the CCM and the pressure drop for clean corn is the predicted airflow resistance of the corn-fines mixture. Fines for the Grama study were mixtures (called grades) of sizes 1-7 (Table 3). Fines proportions were established by screening samples from country-elevator shipments in 1981 and were reasonably close to the average distribution listed in Table 3.

Linear equations related CCM to percentage of fines, as shown in figure 5. The equations represent CCM as successively larger screen sizes are used. Therefore, differences in the slopes of the equations measure the impact of each successive size on airflow resistance. Grade VII is uncleaned corn.

The contribution of each size can be estimated independently of mixing proportions. The general form of the Grama equations (Grama et al., 1984) is:

$$Y_n = X_n K_n + 1 \quad (8)$$

where

Y_n = CCM for grade n

X_n = percentage of grade n fines

K_n = slope for grade n (fig. 5)

as a summation of individual contributions for m individual sizes mixed in fixed set of proportions:

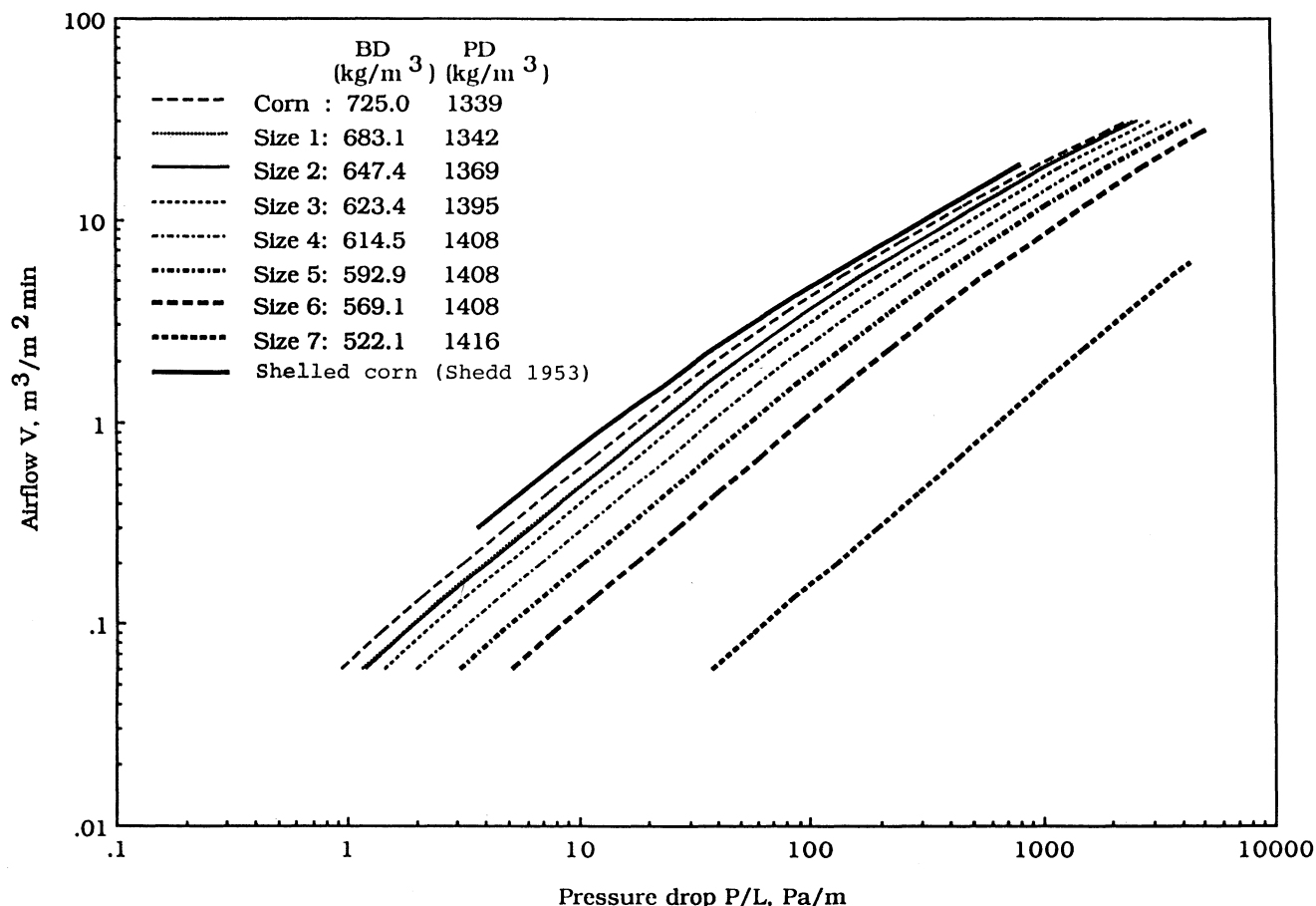


Figure 4—Airflow resistance prediction of clean corn and sized fines (Yang et al., 1990). BD = Bulk density; PD = Particle density.

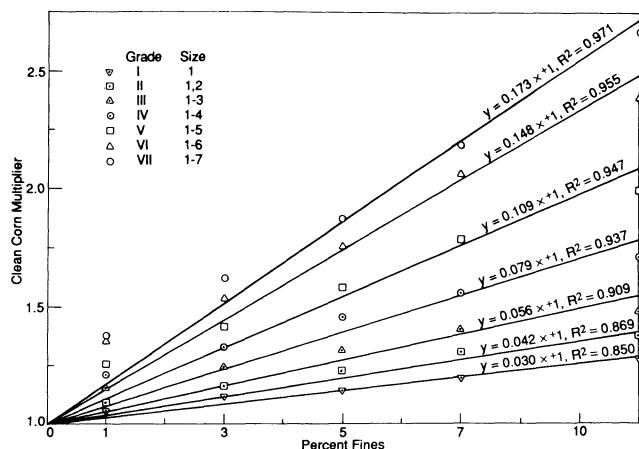


Figure 5—Airflow resistance multiplier for increasing percentages of fines in corn (Grama et al., 1984).

$$Y_n = \sum_{i=1}^m k_i \rho_i + 1.0 \quad (9)$$

where k_i is the contribution of the i th size, dimensionless pack factor units, ρ_i is the percentage by weight of the i th size, in the entire corn sample, and $m = 7$. Equation 9 can be solved successively beginning with Grade I (all size 1, so $K_1 = k_1 = 0.030$), utilizing the fixed relationship of concentrations between sizes. For grade II, sizes 1 and 2 were present, in the proportions of 33:26 (1.269):

$$\rho_1/\rho_2 = 1.269$$

and for $x_2 = 1$:

$$Y_2 = 0.030 (1.269) + k_2(1) + 1.0 = 0.042 (2.269) + 1.0$$

so:

$$k_2 = 0.057, \text{ and so on.}$$

This process yields equation 10 (for $m = 7$, uncleaned corn):

$$Y_7 = 0.030\rho_1 + 0.057\rho_2 + 0.102\rho_3 + 0.256\rho_4 + 0.631\rho_5 + 1.344\rho_6 + 0.648\rho_7 + 1.0 \quad (10)$$

The constants (k_i s) in equation 10 represent the decimal percentage increase in airflow resistance per percentage point of fines in size i . Equation 10 applies to any cleaning situation, because one or more of the ρ_i s can be made zero.

Equation 9, the general case of equation 10, can be modified from equations 1, 2, and the efficiency factor:

$$Y_n = \sum_{i=1}^m \left(\frac{k_i B}{100} \right) (1.0 - E_i) (e^{0.6616 s_i + 1.455}) \quad (11a)$$

or, in conventional units:

$$Y_n = \sum_{i=1}^m \left(\frac{k_i B}{100} \right) (1.0 - E_i) (e^{0.2625 s_i + 1.455}) \quad (11b)$$

Equation 11 estimates the airflow resistance multiplier for cleaned grain, given some initial percentage of BCFM, and a cleaning efficiency for the various particle size.

Fines cause a substantial increase in airflow resistance, and the increase is greater in the smaller sizes than in the larger sizes. The major benefits from cleaning occur from removing material 3.2 mm (8/64 in.) and smaller. Removal of 4.8-mm particles (and smaller) will cut airflow resistance in half. Figure 5 assumed 100% cleaning efficiency for sizes less than the screen size and 0% efficiency for sizes greater than the screen size. In practice, this will not occur (as noted, for example, by Hurburgh et al., 1989). Lesser removal efficiencies for small sizes and some removal of larger fines would flatten out the curves, but the differences between BCFM concentrations would remain.

The airflow resistance, P , in any aeration situation is:

$$P = P_s Y_n k \quad (12)$$

where P_s is the clean corn airflow resistance (any pressure units), and k represents CCM for other conditions. Fan output will be a simultaneous solution of equation 12 and the fan performance curve (output vs. pressure).

Axial and centrifugal crop drying fans are less effective ($\text{m}^3/\text{min-W}$) at greater static pressures (MWPS, 1980). Therefore, increased airflow resistance decreases output and increases energy consumption per unit of airflow delivered. Grama et al. (1984) showed that corn containing 3% BCFM requires from 10% more fan power (for low-airflow, low pressure aeration) to 264% more fan power for low-temperature bin drying) than clean corn containing no BCFM.

Hurburgh (1987) applied this analysis to aeration at grain elevators. No. 2 corn with all BCFM removed showed a \$0.006/bushel/y cost savings over No. 2 corn with 3% BCFM, based on 2,000 h annual fan operation time at $0.1 \text{ m}^3/\text{min-t}$ (0.1 cfm/bu), and electrical energy costing \$0.06/kWh.

PROPERTIES OF CORN DUST

Grain dust is composed of solid particles that become airborne during grain handling. Martin (1981) analyzed grain (including corn) dust collected in dust-control systems of four Kansas elevators.

PARTICLE SIZE DISTRIBUTION

Figure 6 shows the particle size distribution of baghouse and cyclone dust determined by the forward light scatter method. Note that about 5% of this dust is more than $2,000 \mu\text{m}$ (2 mm) in diameter, but that more than 50% is smaller than $100 \mu\text{m}$. Corn dust also contained corn "beeswings" which were 15 to $46 \mu\text{m}$ thick, with a mass of

21.1 to 112 μg and an area of 1.74 to 3.06 mm^2 . Particle density for all the grain dust averaged 1490 kg/m^3 , even more than the density reported for sized fines. The heat of combustion of corn dust was measured at 16.2 kJ/g (6970 Btu/lb), with 81.6% combustibles (combustibles = 100% - % ash - % moisture).

PROXIMATE ANALYSIS

Table 6 shows proximate analysis results for corn (and other) grain dust. Great ash variability was attributed to variability in dirt carried over during harvest. Corn dust stands out as having the least ash, the least crude fiber, and the greatest starch percentages. This is consistent with the Al-Yahya et al. (1991) study that showed that smaller pieces contained more starch.

The last column of Table 5 shows dust nutrient values from Table 6 converted to a dry basis for comparison with other size fractions. Dust stands out as having more ash and fiber than any other fines fraction.

PESTICIDE LEVELS IN DUST

If pesticide has been applied to grain, dust extracted from the grain is likely to have greater pesticide concentrations than the grain. This may occur because dust is produced by abrasion, which loosens surface particles that have absorbed the applied pesticide. Spillman and Parnell (1991) tested corn and corn dust from three elevators to determine Malathion concentration. Corn dust averaged 0.30 g/Mg Malathion, more than 13 times that detected on the corn.

SUMMARY

Properties of fines removed from corn have been reviewed. Properties for which information is found in the literature include constituents, size distribution, nutritive value, economic value, density, and airflow resistance.

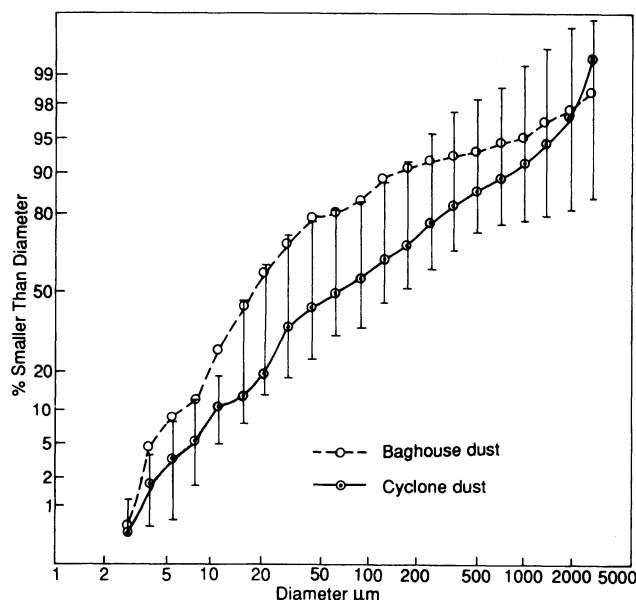


Figure 6—Particle size distribution of grain dust (Martin, 1981).

TABLE 6. Proximate analysis (as-is basis) of dust control system effluent from commercial grain elevators (Martin, 1981)

Dust-Source Grain	Moisture Content (%)	Protein (%)	Ash (%)	Fat (%)	Crude Fiber (%)	Starch (%)
Wheat*	6.5-12.8	7.9-12.2	7.9-28.5	1.6-2.8	15.0-17.2	39.8-55.8
Corn*	11.7-13.5	6.1-8.7	4.1-9.1	1.2-3.6	5.0-10.0	60.9-67.6
Sorghum*	8.0-12.0	5.3-7.8	8.2-32.2	4.0-4.6	8.2-17.3	38.0-61.5
Soybeans†	9.2-11.8	5.9-13.0	12.1-40.5	1.9-2.3	8.8-11.8	33.6-57.7
Mixed‡	9.5	6.5	8.0	4.0	6.8	65.3

* Ranges of four samples.

† Ranges of three samples.

‡ Source, corn and sorghum dust from baghouse, one sample.

1. About 85% of material smaller than whole kernels is broken corn. Noncorn materials are concentrated in sizes less than 4.0 mm (10/64 in.).
2. The relative distribution of particle sizes is constant across the corn market.
3. Cleaners are most efficient at removing smaller sizes of fines.
4. The feed value, as measured by energy content, declines by about 10% as particle size is decreased from whole corn to <1.8mm (4/64 in.). This is not as much as the typical market discount for fines relative to corn.
5. Particle density increases and bulk density decreases as particle size decreases, when measurements are made soon after filling.
6. Presence of fines cause increases of up to 200% in airflow resistance of corn.

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